Chapter 2. Description of Stocks

2.1 Species Description

Squid belong to the class Cephalopoda of the phylum Mollusca. There are approximately 750 recognized species of squids alive today and more than 10,000 fossil forms of cephalopods. They have large, well-developed eyes and strong parrot-like beaks. Squid use their fins for swimming in much the same way fish do, and the funnel for extremely rapid "jet" propulsion forward or backward. The squid's capacity for sustained swimming allows it to migrate long distances as well as to move vertically through hundreds of meters of water in its daily feeding.

Market squid, *Loligo opalescens*, belong to the family Loliginidae. These squid are less than 1/8 inch at hatching and grow to have a mantle length of approximately six inches at the time of spawning. Males are generally larger than females. Squid have eight arms and two longer feeding tentacles (hectocotylus). Male squid use these longer tentacles to pass spermatophores (sperm sacs) to females during mating. Squid arms have suckers and two rows of hooks for gripping mates (Roper and Sweeney 1984). This species is a terminal spawner; spawning occurs at the end of their lifespan, when spawning adults are targeted by commercial fisheries. Recent age and growth information suggests that maximum age is less than one year, and the average age of squid taken in the fishery is approximately six to seven months. Market squid generally have a mixed, iridescent (opalescent) coloration of milky white and purple. The color changes rapidly in response to environmental conditions or possibly for communication. Squid have ink sacs; the ink is a defense mechanism and expelled to confound predators.

Market squid are the focus of the largest commercial fishery in California and are harvested commercially by targeting of spawning aggregations primarily off southern California and Monterey Bay, although some catch occurs throughout their range in other non-directed fisheries. Peak catches occur off southern California during the fall and winter and off central California during the late spring and summer. Though market squid are harvested near the surface and generally considered pelagic, they are actually found over the continental shelf from the surface to depths of at least 2600 feet. They prefer oceanic salinities; squid are rarely found in bays, estuaries, or near river mouths (Jefferts 1983). Adults and juveniles are most abundant between temperatures of 10°C and 16°C (Roper and Sweeney 1984).

The California squid fishery accounts for most of the coast-wide landings; minor amounts of market squid are landed in Canada, Washington, and Oregon. The size of the Mexican fishery is unknown but is also thought to be minor. In California, most squid marketed for human consumption are frozen, but small amounts are canned or sold fresh. Historically, the domestic demand for frozen squid has been relatively minimal, and most of the increased production from California during 1994-2000 was frozen and exported to Europe and China. Market squid are frozen for bait and supplied to domestic commercial and sport fishers, and are also an important source of live bait for the California sport fishing industry.

2.2 Distribution, Stock Biomass, Genetic Stock Structure, and Migration

Market squid are primarily found from the southern tip of Baja California, Mexico (23° N latitude) to southeastern Alaska (55° N latitude). Juveniles and adults range throughout the California Current system (Roper et al. 1984), and paralarvae inhabit the waters closer to the shoreline (Zeidberg et al. 2000). Their distribution is patchy. If squid are found at one site, it is likely that additional squid will be found in close proximity (contagious distribution).

The California fleet currently fishes only adult squid during spawning events in limited geographic areas, in central and southern California. The abundance of market squid at these known fishing areas is dramatically affected by environmental conditions, especially El Niño events (when landings are minimal).

Little is known about the present size, structure, or status of the market squid population, but evidence from research surveys and recent catch data indicate the biomass is large at times. No direct, statistically defendable population estimates are available. It is important to note that the squid population appears to have the ability to recover fully in a relatively short period similar to other short-lived, highly fecund animals.

Genetic analyses have had limited success in distinguishing stocks within a fishery. Gilly et al. (1999) investigated genetic differences between the northern and southern squid fisheries. No temporal or spatial genetic differences for market squid were found within the Southern California Bight. No temporal differences occurred between stocks in the Monterey area. Only slightly significant differences were observed between the southern California and Monterey stocks, suggesting that market squid does not have 100% identity between the two fisheries. Additional genetic research is taking place, focusing on genetic differences at the extremes of the market squid range (Alaska and Baja California) before looking for differences within the range (Monterey and the Channel Islands). Thus, the number of market squid stocks or subpopulations along the Pacific Coast is unknown at this time.

Market squid paralarvae are dispersed off egg bed areas by ocean currents and are most commonly found inshore, concentrated in areas where water masses converge (Okutani and McGowen 1969, Zeidberg et al. 2001). Adult market squid migrate to nearshore areas and form dense aggregations for spawning. Their vertical distribution during daylight hours ranges from 300 to 2000 feet. At night, adults are located within the upper 300 feet of the water column (Zeidberg 2001). The migration patterns of juveniles are unknown, although they are often widely distributed. Midwater trawl surveys in 1999 collected juvenile market squid at 45% of the stations throughout the Southern California Bight (CDFG, unpublished data).

2.3 Age and Growth

Market squid egg hatching rate is determined by temperature, with incubation time ranging from 22 to 90 days at temperatures from 20° to 6°C (Isaac et al. 2001). At water temperatures of 11° to 14°C, found commonly in areas where squid eggs are deposited, incubation lasts from 34 to 52 days.

The age and growth of market squid is determined using statoliths, balance structures analogous to otoliths in fish. Daily ring deposition on statoliths is used to determine the life span of these invertebrates. Deposition of daily rings has been validated for some members of the family Loliginidae and other species of squid; daily ring deposition has been validated for market squid up to 55 days (Hurley et al. 1985; Lipinski 1986; Jackson 1990a, b, 1994, 1998; Bettencourt et al. 1996; Spratt 1978).

Research by Butler et al. (2001) indicate that market squid growth increases with age and is best described with a power function:

$$DML = 0.001342 * Age^{2.132}$$

where DML is dorsal mantle length in millimeters and age is in days ($r^2 = 0.95$, $df = 275$, $P < 0.001$). Paralarvae growth is slow [0.05 mm dorsal mantle length (DML)/day] during the first month, but growth rates increase dramatically as squid mature.

Because the market squid fishery in California targets spawning squid and it is believed that squid die soon after spawning, squid collected directly from fishing vessels at processing docks should represent squid at or very near the end of their life span. From port samples collected from November 1998 through July 2000, 908 statoliths have been aged (Fig. 2-1). The mean age of harvested market squid is 188 days. The average male (190 days) is slightly older than average female (186 days), however the range for females (108 - 302 days) is broader than males (114 – 281 days).

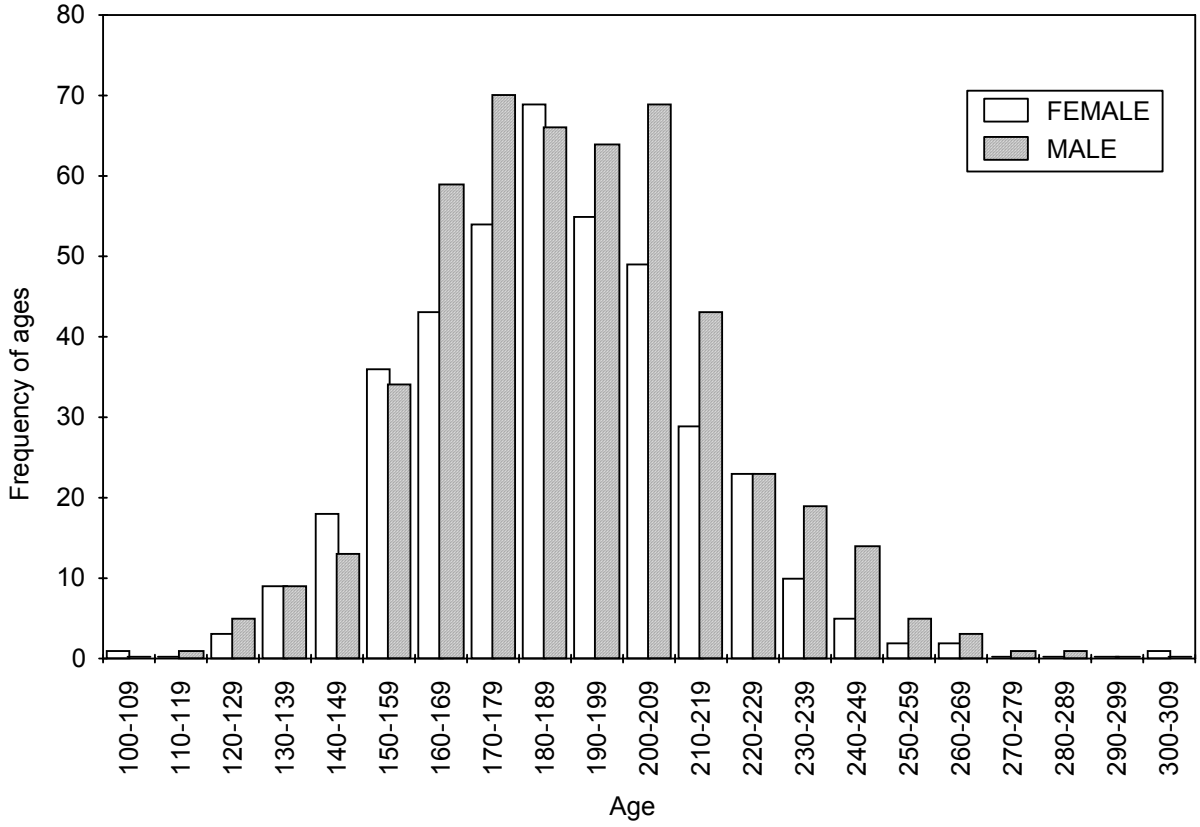

Figure 2-1. Frequency of market squid ages from port samples by sex.

Although the ageing method needs to be validated for *Loligo opalescens* at different life stages, statolith reading provides a reasonable estimate of age. The age data tend to show little variation between months, which strongly suggests that a new cohort enters the fishery monthly. Further, ageing techniques indicate that the average market squid lives approximately six months, but may be sexually mature as early as 3.6 months (108 days) and can spawn as late as 10 months (302 days). Less than one percent (4/908 or 0.4%) of the squid aged could not be sexed, suggesting that sexually immature squid are rare among spawning or harvested squid.

2.4 Reproduction, Seasonality, and Fecundity

Spawning market squid tend to congregate in dense schools, usually over sandy habitats where they deposit extensive egg masses. In central California spawning activity starts around April and ends around October, while in southern California, spawning events begin around October and end in April or May. During some years, however, reproductive activity and landings may occur throughout most of the year. Year-round spawning in several areas statewide at

different times of year likely reduces the effects of poor local conditions on survival of eggs or hatchlings, and suggests that stock abundance is not solely dependent on availability of squid in a single spawning area.

Mating takes place on spawning grounds but may also occur before squid move to their spawning sites. Male squid place spermatophores into the mantle cavity of females and eggs are fertilized as they are extruded (Hurley 1977). Off California, female squid produce 20 to 30 egg capsules – each capsule contains 200 to 300 eggs that are suspended in a gelatinous matrix. The number of capsules and eggs within capsules vary by locale (numbers are reduced in Oregon). Females attach each egg capsule individually to the bottom. As spawning continues, mounds of egg capsules covering more than 100 square meters may be formed, appearing to carpet the sandy substrate. It is well established that market squid die after completing their first and only spawning period (McGowan 1954, Fields 1965), but the duration of the spawning period is unknown.

The realized lifetime fecundity of market squid is a critical life history trait; fecundity must be known to estimate the biomass using either egg deposition or larval production methods (Hunter and Lo 1997). Macewicz et al. (2001) collected female market squid for fecundity and histological analyses during three research cruises (Jan. 1998, Dec. 1998, and Feb. 2000). Their results indicate that squid have a fixed reproductive output and die before developing and spawning all possible eggs in their ovaries. Therefore, the realized lifetime fecundity (F) of female market squid is best estimated by subtracting the residual fecundity (F_r = eggs not deposited) from their potential fecundity (F_p). The preferred estimate of the potential number of eggs an average female market squid produces is 3844, based on a linear model. Residual fecundity (F_r) was estimated at 834 eggs for females with the most advanced ovary, [major axis diameter (D) of the smallest oocyte was 0.771 mm] combined with the poorest condition of their mantle [>50% of the mantle depleted, mantle condition index (C) was 0.323 mg/mm^2]. This model yielded a realized lifetime fecundity ($F = F_p - F_r$) of 3010 eggs.

2.5 Natural Mortality

> The best information available indicates that squid endure very high natural mortality rates and the adult population is composed almost entirely of new recruits. No spawner-recruit relationship has been demonstrated. These observations suggest that the entire stock is replaced annually, even in the absence of fishing. Thus, the stock is entirely dependent on successful spawning each year coupled with good survival of recruits to adulthood.

Full recruitment of market squid into the fishery occurs at six months, and data from squid aged six to 10 months were used to estimate total mortality (natural

and fishing) resulted in a range of 0.3 to 0.6 per month. Thus, monthly natural mortality is less than 0.6 (STAR Panel Report, 2001).

2.6 Disease

Little is known about parasitic infestation of market squid. Several marine worms utilize the squid as a host species; nematodes, cestodes, and polychaetes all have been recovered from squid and/or squid eggs. Nematodes (roundworms), cestodes (tapeworms), and their larval stages have been found in market squid (Benjamins 2000). In Monterey Bay, Riser (1949) cited infestation of squid by two types of plerocercoid larvae. These larvae are tetraphyllidean cestodes that infest the large intestine of the squid. At Point Mugu, squid sampled from a commercial seafood outlet exhibited infestation by larval cestodes (orders Tetraphyllidea and Pseudophyllidea) and nematodes. These parasites were found to infect the eye, stomach, intestines, body cavity, and tissues at a rate of 76.9% (Dailey 1969). The polychaete worm *Capitella ovincola* may or may not be a parasite of market squid eggs. This worm has been found inside squid egg capsules (MacGinite and MacGinite 1949) and may affect squid fitness either by decreasing the egg hatching rate or triggering premature hatching (Morris et al. 1980).

2.7 Predator/Prey Relationships

Market squid feed on a variety of prey during their life cycle. As larvae and juveniles, squid focus on copepods and euphasiids as prey; these fast-moving prey items are a challenge to young squid and enhance the development of prey-capture and escape skills (Preuss and Gilly 2000). As adults, market squid feed on fish, polychaete worms, other squid (cannibalism), and crustaceans such as shrimp and pelagic red crab. Squid are found in commercial catches of anchovies, sardines, herring, mackerel, and sauries; they feed with and most likely upon these fish (Fields 1965). In Monterey Bay, larger squid have been found to feed more on fish and cephalopods; however, there are more significant differences in prey intake at distinct depths and locations than between size classes (Karpov and Cailliet 1979).

Prey composition fluctuates with not only squid age, size, and reproductive status, but spatially as well – availability of prey and the behavior of market squid at different depths and locations may influence feeding behavior. Karpov and Cailliet (1978, 1979) found that crustaceans and cephalopod fragments were ingested at higher frequencies on spawning grounds than on non-spawning grounds. In deeper waters, euphasiid and copepod feeding dominated, while true cannibalism (intake of whole cephalopods) and fish intake peaked in shallow waters. Inshore versus offshore samples of squid also indicated a difference in diet.

Market squid are an integral part of the food web to many marine vertebrates. Fish, birds, and marine mammals all utilize the availability of squid as a prey item, though predators that share its habitat range are most likely to feed upon it. In Monterey Bay, 19 species of fish were found to feed upon market squid, including many commercially important species such as Pacific bonito, salmon, halibut, and tuna (Fields 1965; Morejohn, Harvey, and Krasnov 1978). Market squid are used as bait in some of these commercial fisheries – they are the primary invertebrate bait for commercial and recreational fishermen of adult white seabass in California waters (WSFMP 2002). Seabirds such as the common murre, ashy storm-petrel, black storm-petrel, fork-tailed storm-petrel and rhinoceros auklets feed on market squid, and it is the primary prey item in the diet of harbor porpoises in Monterey Bay (Lowry and Caretta 1999). Squid also factors into the diets of the sea otter, elephant seal, northern fur seal, California sea lion (Lowry and Caretta 1999), Dall's porpoise, Pacific striped dolphin, and toothed whales such as the short-finned pilot whale (Hacker 1992), and the sperm whale and bottlenose whale (Fields 1965).

Opportunistic invertebrates such as the spiny brittle star (*Ophiothrix spiculata*) have also been known to prey on market squid. Sandy bottom habitat attracts dense aggregations of brittle stars (millions can cover a small area of the sea floor) and spawning squid alike. Observations of multiple brittle stars attacking egg cases and live squid have been made off Anacapa Island; however, there is no evidence of actual ingestion of squid (Lazar pers. comm.).

Just as availability of prey affects squid foraging, the changing abundance of squid affects potential predators. Short-finned pilot whales, blue sharks, and Pacific bonito all increase their consumption of market squid during spawning season. It has been suggested that short-finned pilot whales in the Southern California Bight (Hacker 1992) and blue sharks near Santa Catalina Island (Tricas 1978) may move inshore as the squid spawning season begins; Pacific bonito consumption of squid is influenced by the shoaling behavior of squid spawning in nearshore waters of southern California (Oliphant 1971).

The El Niño Southern Oscillation appears to alter the availability of market squid as a prey item for pinnipeds. During an El Niño event, the presence of market squid in California sea lion and Pacific harbor seal scat samples decreases more than three-fold (Henry 1997) as compared to non-El Niño periods.

2.8 Competition

Market squid feed with a variety of pelagic fish, namely anchovies, sardines, herring, and mackerel, and are often taken up in commercial catches of these species; however, there is little information regarding actual competition for resources. Dense spawning aggregations of market squid may result in an increased incidence of cannibalism (Karpov and Cailliet 1978) due to competition for space. Observations off Anacapa Island suggest that competition for space

between spawning squid and the spiny brittle star may occur on the seafloor; dense aggregations of brittle stars occur on prime spawning grounds.

Trophic interactions between squid and higher-trophic-level fish are poorly understood. It is not known if the value of market squid CPS as forage to adult predators outweighs the negative effects of predation by squid on larvae and juveniles of predator fish species plus competitive removal of phytoplankton, zooplankton, and other fish.

2.9 Critical Habitat

The description and identification of Essential Fish Habitat for market squid is generalized because few data are available for this species. The CPS FMP describes the east-west geographic boundary to be "all marine and estuarine waters from the shoreline along the California coast offshore to the limits of the exclusive economic zone (EEZ) and above the thermocline where sea surface temperatures range between 10º C to 26º C, the upper tolerance of CPS finfish."

Market squid inhabit the inshore and offshore waters of the Pacific Ocean from British Columbia down to Baja California, specifically within the California Current. The California Current is a region of transport, coastal jets, divergence and upwelling. Changes in the Pacific Basin atmosphere pressure systems result in seasonal and interannual environmental variability within the California Current ecosystem. Variations are caused by local winds and Ekman transport, flows of the equatorward California Current, the poleward undercurrent, and the inshore countercurrent. Temporal variations associated with the California Current are on time scales of several years to decades [i.e., the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO)]. ENSO and PDO events markedly alter flow and temperature of currents within the California Current system.

Refuges, preserves, and marine sanctuaries are areas that are legally defined and regulated by the State or federal government, with the primary intent of protecting marine resources for their inherent biological or ecological value. Two national marine sanctuaries, the Channel Islands National Marine Sanctuary and the Monterey Bay National Marine Sanctuary, out of 11 nationwide, are the main fishing areas for market squid.

Juvenile and adult squid range throughout the California Current system (Roper et al. 1984), and paralarvae inhabit the waters closer to the shoreline (Zeidberg et al. 2000). Market squid are pelagic and believed to be associated with the Deep Scattering Layer which migrates vertically to the upper levels of the water column diurnally. Market squid are harvested near the surface. Spawning squid concentrate in dense schools near spawning grounds but habitat requirements for spawning are not well understood. Spawning occurs over a wide depth range, but the extent and significance of spawning in deep water is unknown.

Known market squid spawning grounds are characterized by muddy sand in shallow waters; major spawning grounds fished in California are found in Monterey Bay and the Channel Islands. Egg cases are most often deposited at depths between 60 and 180 feet (Kudroshoff et al. 2000), but have been found at depths of 2600 feet. They prefer oceanic salinities; adults and juveniles are most abundant between temperatures of 10º and 16ºC (Roper et al. 1984).

2.10 Status of the Stocks

Market squid population dynamics are poorly understood. Annual fluctuations in the commercial squid catch may reflect squid abundance patterns rather than just local availability, but this idea has not been substantiated. Although some information exists on coastwide market squid distribution and abundance from fishery-independent midwater and bottom trawl surveys aimed at assessing other species, there is no good measure of annual recruitment success beyond information obtained from the fishery. As fishing activity occurs only on shallow-water spawning aggregations, it is not apparent if reduced landings reflect only a decline in availability to the fishery, or if overall stock size is diminished, since squid have been commonly documented at greater depths using other gear methods.

Historically, the squid resource was considered by some to be underutilized. Recently (during El Niño periods), demand has sometimes exceeded the catch. Until improved estimates of abundance are available, the true status of the population will remain unknown. Past work has included acoustic surveys and various collection techniques. Acoustical assessment of squid has been attempted off the central Oregon coast (Jefferts et al.1987). However, with the scientific research program initiated in 1998, efforts to model the population began which may eventually give rise to thorough and detailed stock assessments similar to those undertaken for other coastal pelagic species.